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LIGHTNING STRIKE SUSCEPTIBILITY TESTS ON THE AIM-9 MISSILE

*TECHNOLOGY/SCIENTIFIC SERVICES, INC.
AIR FORCE FLIGHT DYNAMICS LABORATORY (AFFDL)
ELECTROMAGNETIC HAZARDS GROUP (FES)*

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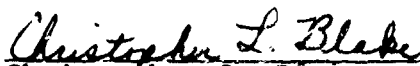
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This technical report has been reviewed and is approved for publication.



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Lightning strike susceptibility tests were conducted on AIM-9 missile forward sections to evaluate possible interface problems with the F16 aircraft. High voltage attachment, streamer-ing and high current arc tests were performed using the specialized test facilities and instrumentation of the Air Force Flight Dynamics Laboratory. It was experimentally determined that the optical dome/zinc-coated fiberglass interface at the forward end is the →			

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20. → most probable attachment point to the AIM-9 missile. The optical dome was found to be highly vulnerable to direct lightning strikes but there is no evidence that lightning will penetrate the F-16 aircraft via the AIM-9 missiles. The operational status of the AIM-9 missile subsequent to a direct lightning strike is suspect; however, complete evaluation of this subject was beyond the scope of the program. ↗

FOREWORD

This report describes a lightning strike susceptibility test effort conducted by the Electromagnetic Hazards Group (FESL), Survivability/Vulnerability Branch, Vehicle Equipment Division, Air Force Flight Dynamics Laboratory (AFFDL), Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, under Project 75000300, "Atmospheric Electricity Hazards Research Facility Miscellaneous Support".

The tests were performed during the period October - November 1977 under the direction of Christopher L. Blake (ASD/ENA), project engineer for the Aeronautical Systems Division and Vernon L. Mangold (AFFDL/FESL), project engineer for AFFDL. The principal investigator was Lawrence C. Walko of Technology/Scientific Services, Inc. (T/SSI), Dayton, Ohio. The report was released by the authors in March 1978. The test program was supported by personnel from the Electromagnetic Hazards Group and T/SSI. On-site contractor support was provided by T/SSI under Contract F33601-75-C-0120.

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SECTION I

INTRODUCTION

Studies of lightning-induced voltages in an F-4H aircraft using simulated lightning input waveforms identified the wing pylon mounted AIM-9 missile as a point at which lightning could enter the aircraft and possibly damage or upset flight critical aircraft equipment (Reference 1). Actual inflight lightning experience with the AIM-9 missile is very limited (one USAF incident is reported in Reference 2). The minimal data available indicate lightning will generally attach in close proximity to the optical dome (the nose cone of the missile). Also, review of the missile design (Reference 3) led to the conclusion that attachments to other areas of the missile should not provide a through-path for lightning entry into the aircraft. It was considered essential to evaluate possible F-16/AIM-9 (Figure 1) interface problems due to lightning since the few actual lightning strikes to missiles of this type are not documented. The Electromagnetic Hazards Group was tasked by the U.S. Air Force Systems Command (AFSC), Aeronautical Systems Division (ASD) to perform the tests.



Figure 1. AIM-9 Missiles Mounted on an F-16 Aircraft

SECTION II

OBJECTIVE

The purpose of these tests was to determine the possibility of lightning entry into the F-16 aircraft via the AIM-9 missile. The concern was that a lightning strike could attach to the AIM-9 missile, penetrate the missile body, find an electrical path into the aircraft and subsequently disturb the flight control system or other critical electronic circuitry.

To satisfy this objective the following questions were to be answered during these tests:

- a. Will lightning attach directly to the glass optical dome?
- b. Will lightning attach to the zinc-coated fiberglass optical assembly housing located directly aft of the dome?
- c. Will lightning damage, or destroy, the dome or housing?
- d. Will lightning enter the missile and seek a path through the missile electronics to the umbilical connection to the aircraft?
- e. Can any other information be collected which may be used to further assess damage potential?

To answer these questions the following tests were accomplished on two identical AIM-9 missiles (forward sections):

AIM-9J Guided Missile, S/N AJ 1355M

AIM-9J Guided Missile, S/N RLP 23372

SECTION III

SUSCEPTIBILITY TESTS

1. High Voltage Attachment Arc Test

This test was performed to answer questions IIa and IIb and to document the point of attachment of the lightning arc on the missile. To accomplish this, a Marx type impulse generator (Figure 2) with a high voltage peak output of approximately 700 kilovolts generated an arc, one meter in length, to the front part of the missile. The attachment was documented by cameras set at 90° to each other as specified in design note 7C2 of Reference 4.

To provide information on all possible angles of lightning approach to the missile, the high voltage output electrode of the Marx generator was positioned as shown in Figure 3, providing a 90° sweep at 15° intervals in the vertical and horizontal planes. The 90° sweep is sufficient since the missile is axially symmetric in the planes for which lightning attachment tests were performed.

2. Streamering Tests

To study the high voltage streamering effects on the AIM-9 missile prior to arc breakdown, the tail of the missile was hardwired to the output of the Marx generator. A grounded metal plane, 30" x 32", was placed perpendicular to the extended axis of the missile and facing the optical dome. The gap between the dome and the plane was of such a length as to permit streamering off the front of the missile but not flashover. This test provides further information to answer question IIe.

3. High Current Tests

a. Intermediate High Current and Induced Voltage Measurements

To answer questions IIId and IIe and to obtain information on levels of voltage and current induced by lightning current on the internal electrical circuitry, the missile was hardwired to

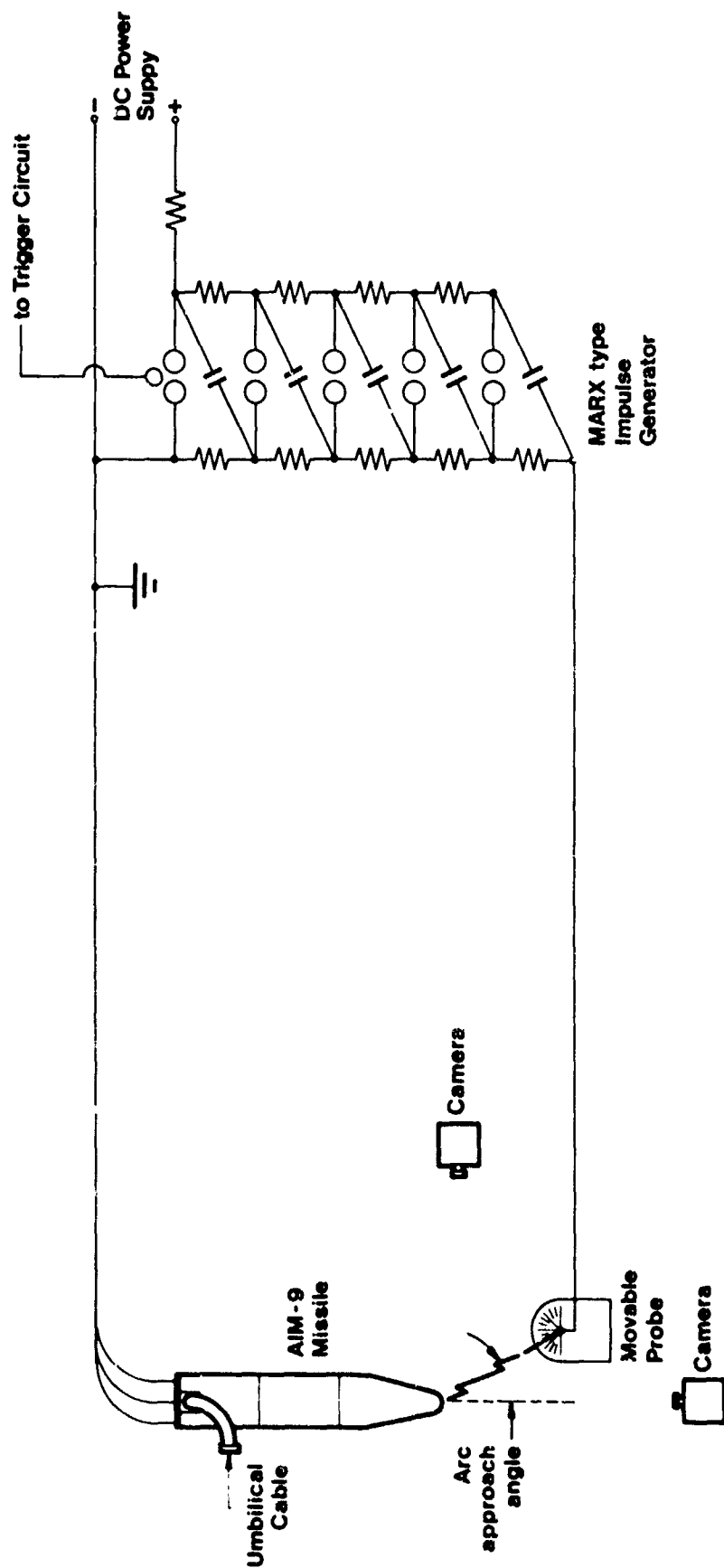


Figure 2. High Voltage Attachment Test Setup

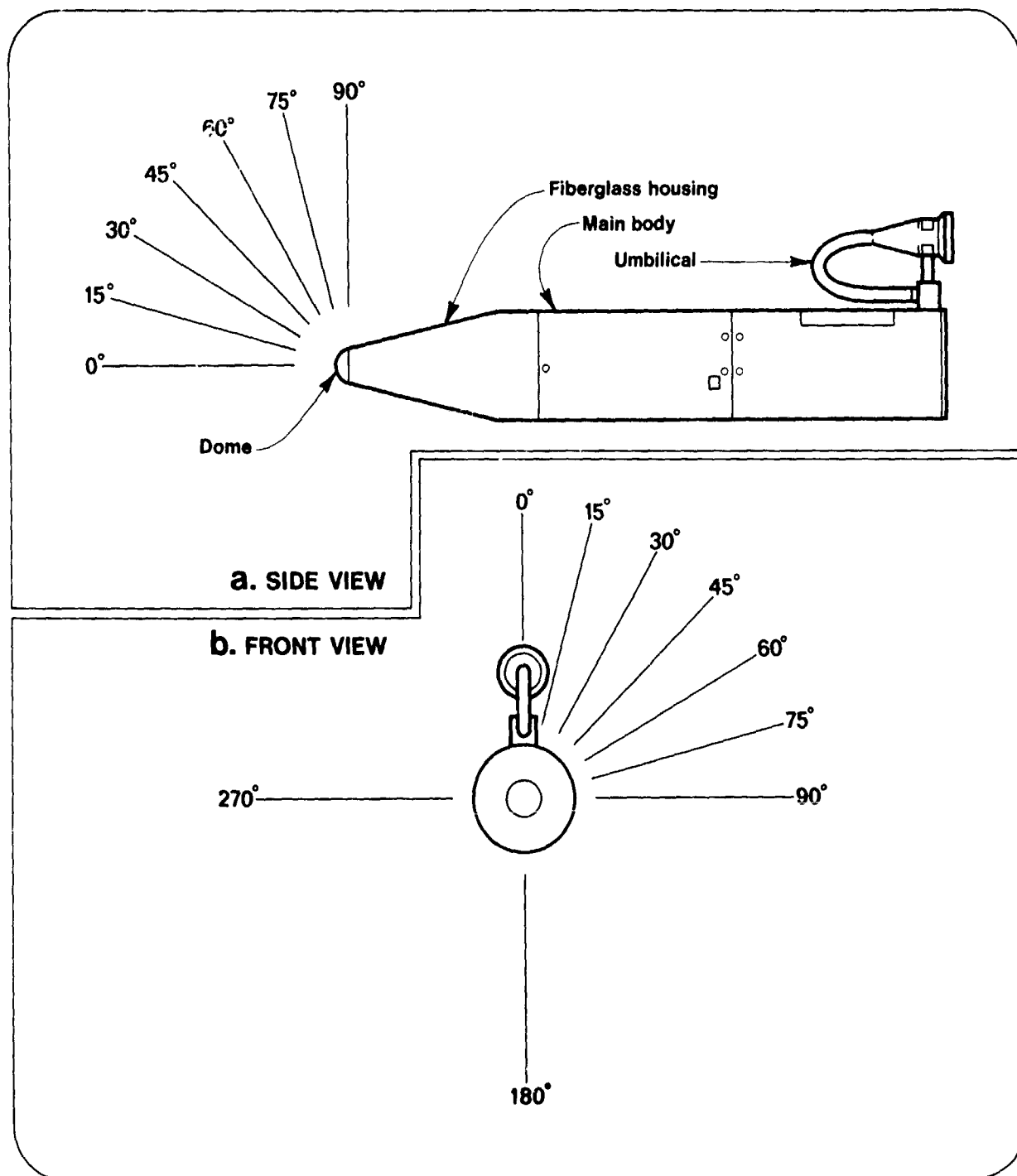


Figure 3. Electrode Locations for High Voltage
Arc Attachment Tests of AIM-9 Missile
(Horizontal and Vertical Planes)

the output of a high current impulse generator (lightning simulator), thus preventing external damage. An output current impulse of approximately 12 kiloamperes peak (Fig. 5) was injected along the missile body. Using a fiber optics data link, voltages induced during the test were monitored on selected circuits (based on the findings of Reference 1), inside the missile. Access to these circuits was gained through the umbilical cable on the missile. Figure 4 shows the test setup.

Induced voltage measurements were made on the following circuits on the umbilical cable:

1) Conductors S-V, CDU Power & Servo Heater - Ground

This line is a 28 VDC line directly into the aircraft. The line runs the full length of the missile and supplies power to the servo heater and to the TE cooler mounted next to the IR detector in the seeker assembly. The circuit is isolated by a relay from the aircraft until the missile is activated and is connected inside the aircraft to a circuit breaker panel supplying the main power.

2) Conductors D-V, Precession Amplifier Filament-Ground

This circuit supplies voltage to all missile internal circuitry (active). Power for this line is derived from a power supply in the launcher itself that converts 115 volts, 400 Hertz, from the aircraft to 28 volts DC. This supply is isolated from direct connection to the missile electrical/electronic circuits by the power transformer and regulation circuitry.

3) Conductors J-V, Gas Grain Squib - Ground

This is a 28 VDC power line which activates the gas grain generator providing initial inflight power to the missile guidance and control circuits. Excessive voltage on this line could cause detonation of the gas squib. This alone would not launch the missile but it would render the missile useless because of consumption of the inflight power supply.

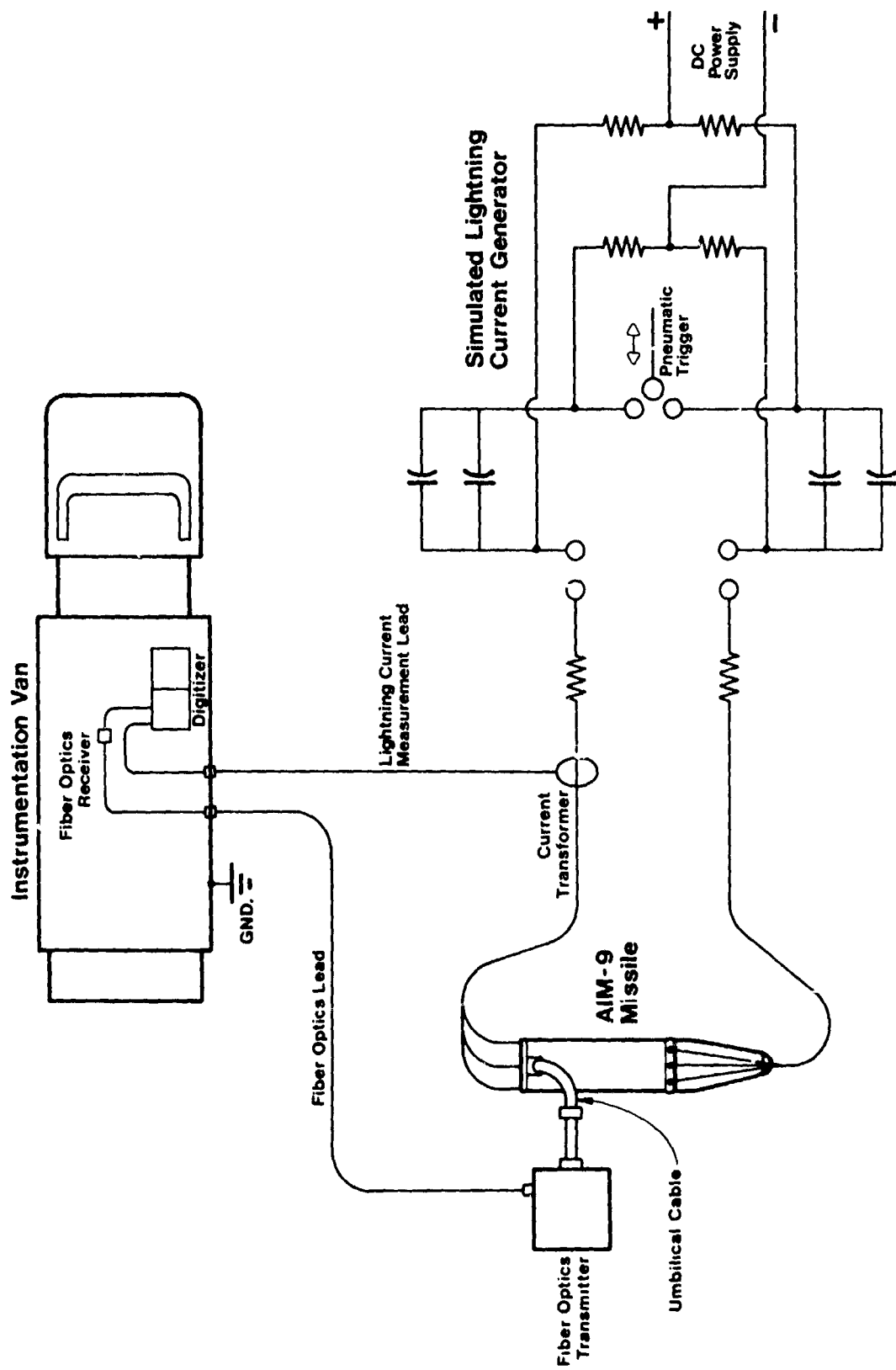


Figure 4. Intermediate High Current Test Setup

b. High Current Arc Tests

After the intermediate current tests were completed, the missile was subjected to high current arc tests with the optimum electrode position determined from the high voltage attachment tests. This test was used to determine the damage tolerance (question IIc) of the missile when struck by a full scale lightning flash. Since the test was intended ultimately to be destructive, it was performed last.

SECTION IV

DATA RECORDING AND PROCESSING

All applied current/voltage waveshapes and all induced transient voltages were monitored and recorded using a Transient Waveform Digitizer System. The major components of this system were the Tektronix R7912 Transient Digitizer, PDP-11/05 minicomputer, floppy disc drive, Tektronix 4010-1 graphics terminal and Tektronix 4610 hard copy printer.

The R7912 Transient Digitizer is a high speed analog-to-digital converter that is operated like an oscilloscope, with its output either viewed on a TV monitor or fed into the minicomputer. Coupled with a 7A19 Vertical Amplifier plug-in and 7B92A Horizontal Time Base, the digitizer has a bandwidth of 500 megahertz.

The PDP-11 computer controls the Transient Digitizer or performs normal computations using BASIC language. With Tektronix software (SPS TEK BASIC) and additional programs written specifically for simulated lightning investigations, this system provides a data storage and analysis capability superior to other systems in use, such as oscilloscopes.

The graphics terminal can display numerical and graphics information and the hard copy unit can make permanent repeat quality copies of this information. Data storage is accomplished using floppy disc or cassette tapes.

The fiber optics measuring system, coupled with the transient digitizer, was used to monitor the induced voltages on the missile circuitry. This eliminated the need for hard wire connections from the missile circuitry to the digitizer, reducing extraneous noise pickup levels and eliminating current ground loops.

This instrumentation is highly suitable for use in measuring lightning-induced voltages using the simulated lightning test technique described in Reference 5.

SECTION V

RESULTS

1. High Voltage Arc Attachment Tests

Table 1 summarizes the results of these tests and photographs of the arc attachment to the AIM-9 missile are presented in Appendix A. The significant results of the eighteen tests conducted are:

a. In all but one case, attachment was only to the interface of the optical dome and the zinc-coated fiberglass housing.

b. In the one case of attachment to the optical dome there was a surface flash-over to the zinc-coated fiberglass housing, with no penetration of the optical dome. Prior to attachment (Figure A-18) the arcs branched and attached to the dome and to the dome/housing interface.

c. Arcing was observed around the screw heads at the interface of the zinc-coated fiberglass housing and the metallic (main-body) missile housing. This is due to the arc current flowing along the zinc surface coating and the screws providing the lowest impedance path to the metallic main body of the missile which was grounded.

2. Streamering Tests

Three tests were conducted to determine the streamering of the AIM-9 missile. The photographs of the streamering tests are presented in Appendix B. In each case streamering was evident off the rim at the interface where the optical dome mates with the zinc-coated fiberglass housing.

3. High Current Tests

a. Intermediate High Current and Induced Voltage Measurements

The current impulse applied to the missile for these tests is shown in Figure 5. It had a peak current of approximately 12 kiloamperes with a rise-time of 1.3 microseconds.

Table 2 lists the voltage levels measured on the specific circuits as identified in 3a.

TABLE 1
SUMMARY OF LIGHTNING ARC ATTACHMENT TESTS
(Charge Voltage 30 Kilovolts, Arc Voltage 700 Kilovolts)

Test No	Probe Location		Length of Arc (Meters)	Attachment Point (Approx.)	Figure No	Remarks
	Angle(°)	Plane				
1	90	Horiz	1.0	Dome/fiberglass housing interface	A-1	No noticeable damage
2	90	Horiz	1.0	Dome/fiberglass housing interface	A-2	Pitting at interface, flash-over at fiberglass housing/mainbody interface, burn marks on screws
3	75	Horiz	1.0	Dome/fiberglass housing interface	A-3	Flash-over at fiberglass housing/main-body interface
4	60	Horiz	1.0	Dome/fiberglass housing interface	A-4	Pitting at fiberglass housing/main-body interface, burn damage to screws on backside
5	45	Horiz	1.0	Dome/fiberglass housing interface	A-5	No noticeable damage
6	30	Horiz	1.0	Dome/fiberglass housing interface	A-6	Flash-over and pitting at fiberglass housing/main-body interface, burn damage to screws
7	15	Horiz	1.0	Dome/fiberglass housing interface	A-7	No noticeable damage
8	0	Horiz	1.0	Dome/fiberglass housing interface	A-8	Major burn marks on screws on backside, pronounced burn mark at attachment point
9	0	Horiz	1.0	Dome/fiberglass housing interface	A-9	Burn mark on underside of missile at fiberglass housing/main-body interface
10	0	Horiz	1.0	Dome/fiberglass housing interface	A-10	No noticeable damage
11	0	Horiz	1.0	Dome/fiberglass housing interface	A-11	No noticeable damage
12	90	Vert	0.95	Dome/fiberglass housing interface	A-12	No noticeable damage
13	75	Vert	0.914	Dome/fiberglass housing interface	A-13	Burn mark at attachment point and top screw of fiberglass housing/main-body interface
14	60	Vert	0.914	Dome/fiberglass housing interface		Burn mark at attachment point
15	45	Vert	0.80	Dome/fiberglass housing interface	A-15	Burn mark at attachment point, burn marks on bottom screw of fiberglass housing/mainbody interface
16	30	Vert	0.80	Dome/fiberglass housing interface	A-16	Burn mark at attachment point and screws of fiberglass housing/main-body interface
17	15	Vert	0.80	Dome/fiberglass housing interface	A-17	Burn damage at attachment point and screws on back side of fiberglass housing/main-body interface
18	0	Vert	0.51	(Optical) dome and dome/fiberglass housing interface	A-18	No noticeable damage, arc branched and attached to dome at 0° and to dome/housing interface at 180°

Maximum = 11.8321 K AMP
Rise Time = 1.3234 U S

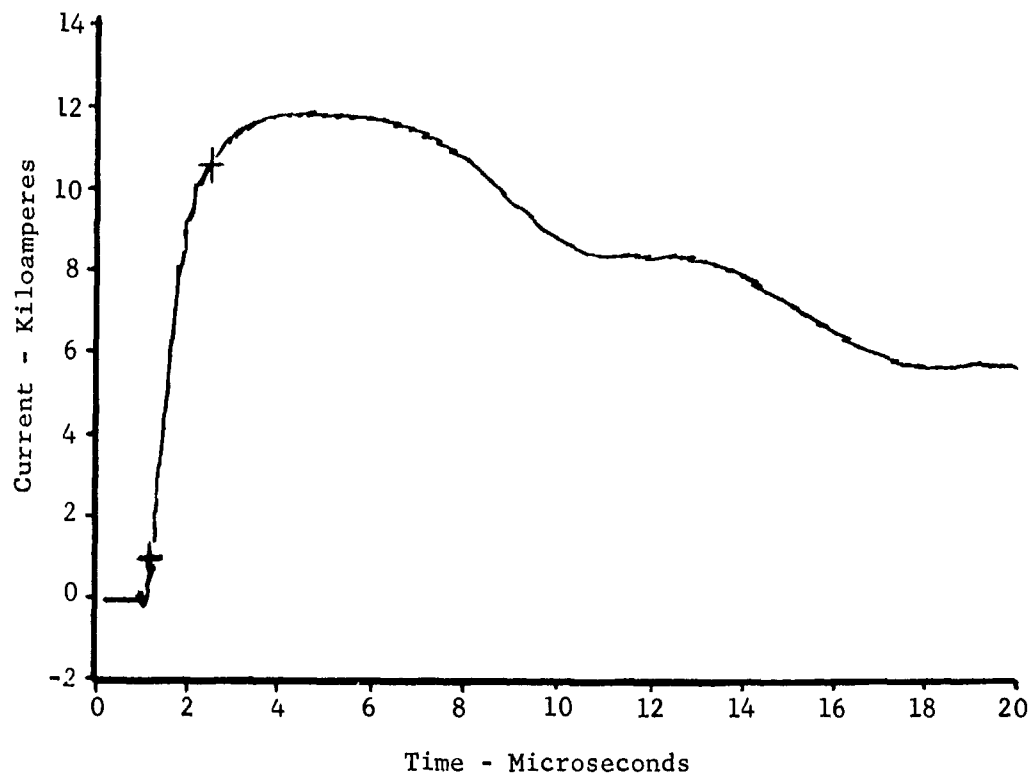


Figure 5. Applied Current Impulse to
AIM-9 Missile for Induced Effects Measurements

Table 2

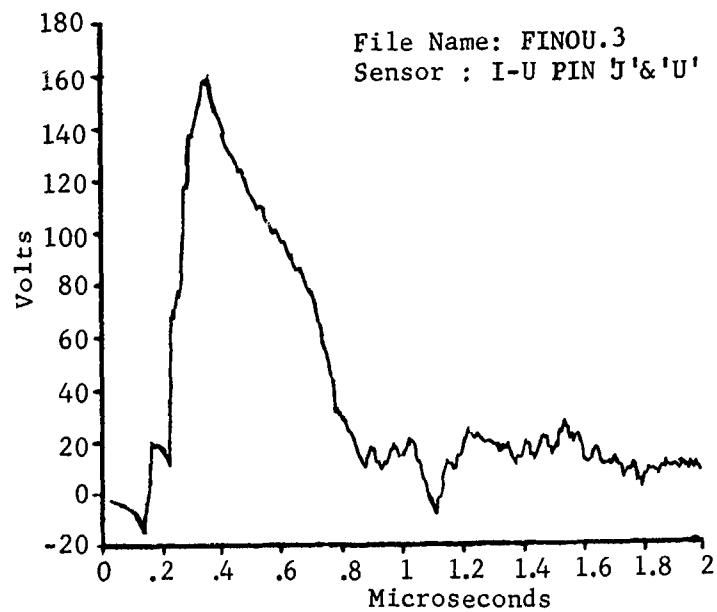
Voltage Levels Measured on AIM-9 Missile Circuits

Circuit Conductors	Induced Voltage - Volts	
	Unshielded Umbilical	Shielded Umbilical
S-V	73.4	--
D-V	70.0	0.48
J-V	150.0	0.40

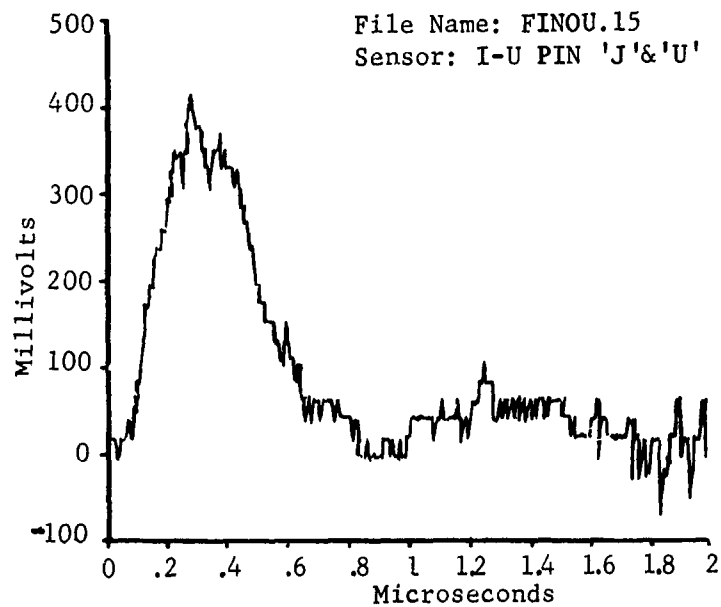
The initial induced voltage measurements were made on the umbilical cable without shielding. Subsequently it was realized that the umbilical cable is shielded by the pylon in a normal aircraft installation. The setup was modified by shielding the cable with aluminum and the measurements repeated. Significantly lower voltage readings were obtained. From this it was speculated that the higher voltage readings were the result of voltages induced on the unshielded cable by the time-varying electromagnetic field rather than by the skin currents on the missile surface, and that the voltage induced by the skin current would be low as indicated by the second set of measurements.

The addition of the foil drastically reduces the electrical field or E-field coupling on the circuitry. However, the addition of the foil also creates a path for the simulated lightning current to flow in close proximity to the unshielded conductors within the umbilical, so that the influence of the magnetic field or H-field created by this current increases. What effect this increase would have on the circuitry is not known since insufficient induced current measurements were made on the cable circuits.

Figure 6 is a comparison of the induced voltage magnitude and waveshape measured on conductors J-V. The large reduction in voltage magnitude (volts to millivolts) due to the addition of foil shielding around the umbilical cable is evident.



a. Without Shielding



b. With Shielding

Figure 6. Comparison of Induced Voltages on Conductors J - V
With and Without Shielding on Umbilical Cable

b. High Current Arc Tests

Both missiles were subjected to high impulse currents to observe the amount of damage created by the high current arc to the nose of the missile. A peak current of approximately 80 kiloamperes (approximately 93 percentile per Reference 6, Figure 24) was applied to the AIM-9 missile (S/N AJ 1355M) with an arc length of 8 inches. This current value was selected based on an engineering judgment that the missile would be susceptible to damage at this level. The test setup used is shown in Figure 7. With this long arc the mechanical blast effect of a high current impulse due to electrode confinement across a small gap was reduced and the cause of the damage was limited to high current effects. Figure 8 is the applied current waveshape. The complete front of the wave is not shown due to late triggering of the transient digitizer system. The rise-time of the applied current wave was graphically calculated to be 25 microseconds.

On missile S/N AJ 1355M the optical dome was shattered and extreme discoloration and burn marks were observed on the zinc-coated fiberglass housing and around the screw heads at the fiberglass/metal interface.

With the thought of reducing the amount of damage to the second missile, S/N RLP 23372, the peak applied current was reduced to approximately 33 kiloamperes (approximately 72 percentile per Reference 5, Figure 24). This current level approximates an average lightning return stroke. Figure 9 shows the applied current waveshape. Again, the optical dome was shattered and discoloration and burn marks were observed in the same areas as on the first missile. Figure 10 shows the damage done to the front part of both missiles. The destruction of the dome is clearly evident.

Both missiles were disassembled and examined for evidence of internal high current arcing. Figures 11 and 12 show no evidence of arcing on any part internal to the missile. If the simulated lightning currents had entered the missile, via the cracked dome, evidence of arcing would have been found either on the inside of the optical housing, the gyro assembly or on circuit cards. None was found.

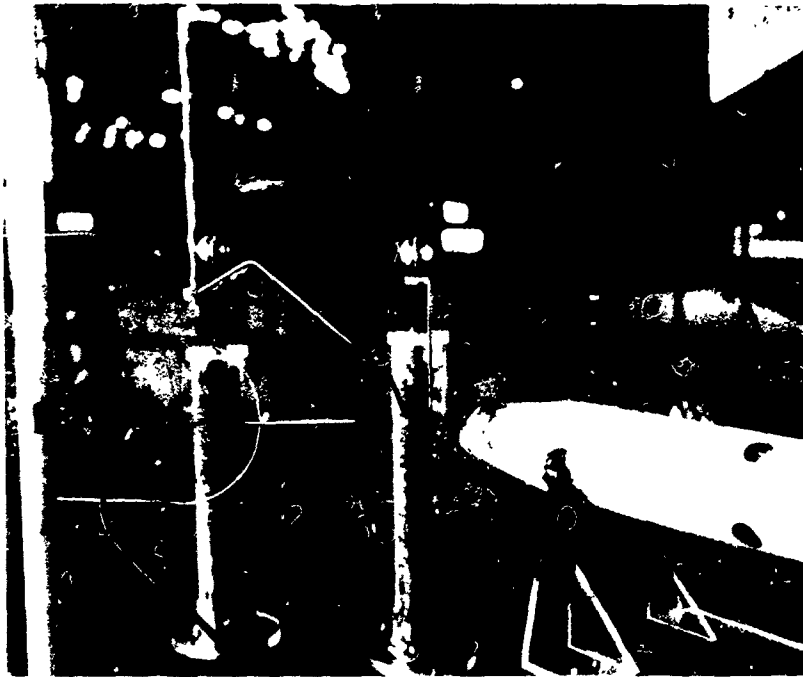


Figure 7. Setup for High Current Tests
Showing Gap Spacing for Tesla Coil Trigger

File Name: FINOU.1
Sensor: Applied Curr.

Maximum = 79.8677 K AMP

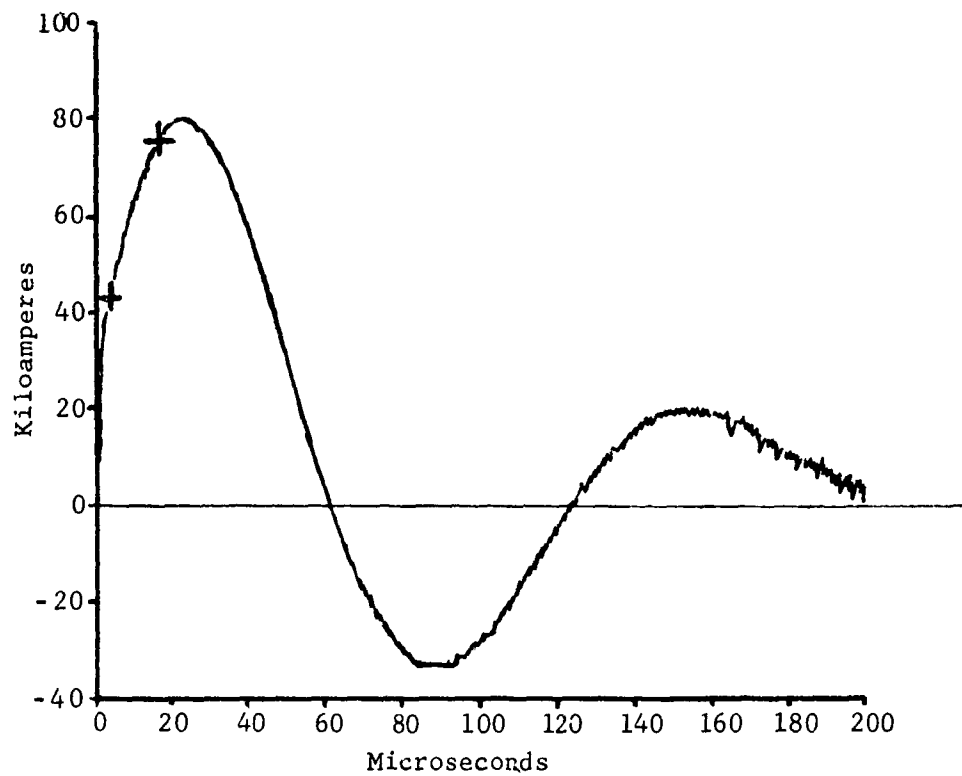


Figure 8. Applied Current Wave to
AIM-9 Missile S/N AJ1355M

File Name: FINOU.3
Sensor: Applied Curr.

Maximum = 32.5672 K AMP

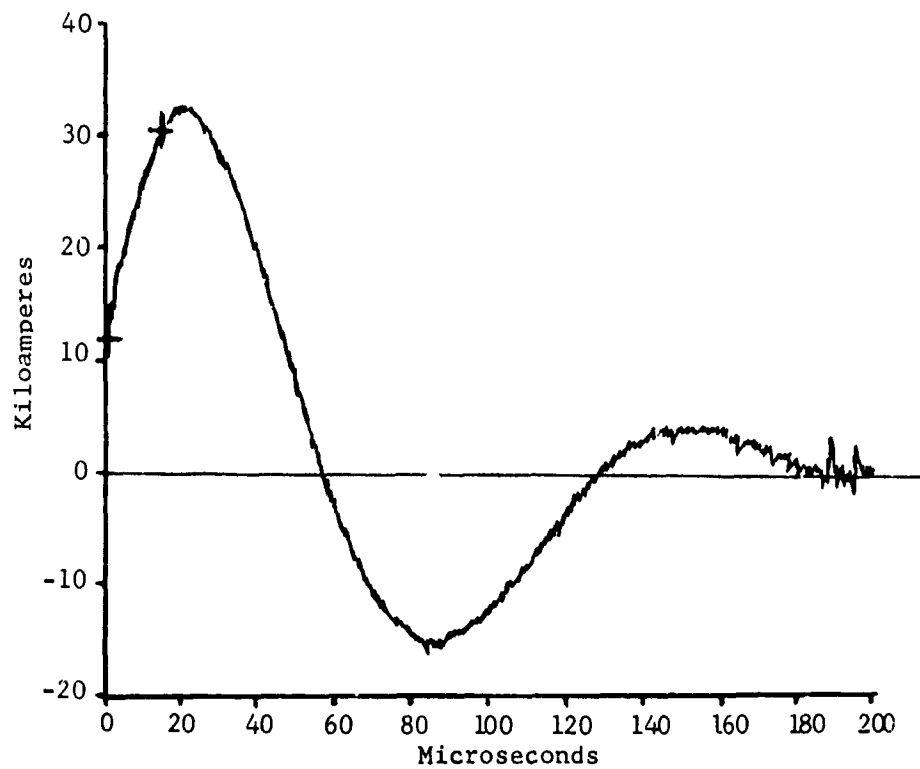
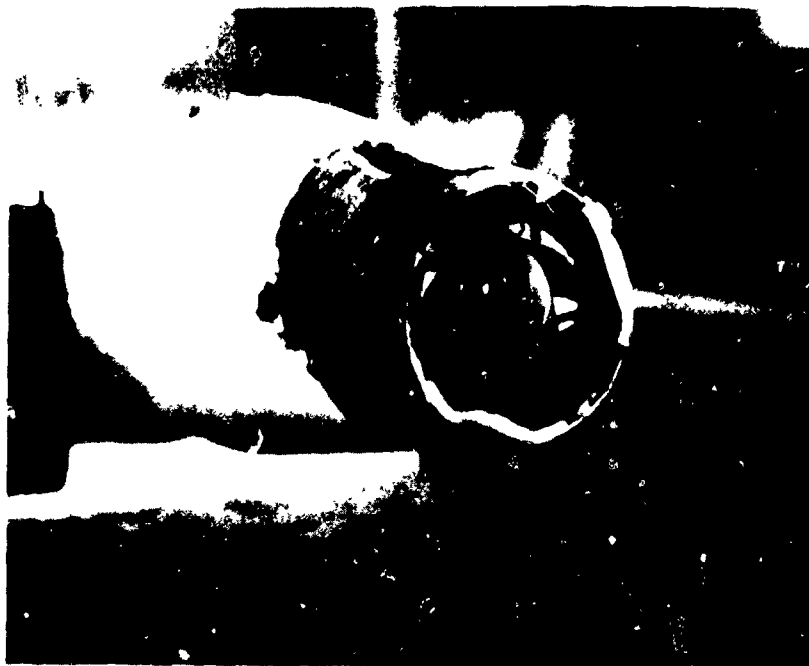


Figure 9. Applied Current Wave to
AIM-9 Missile S/N RLP23372



a. AIM-9 S/N AJ 1355M
80 kiloamperes applied

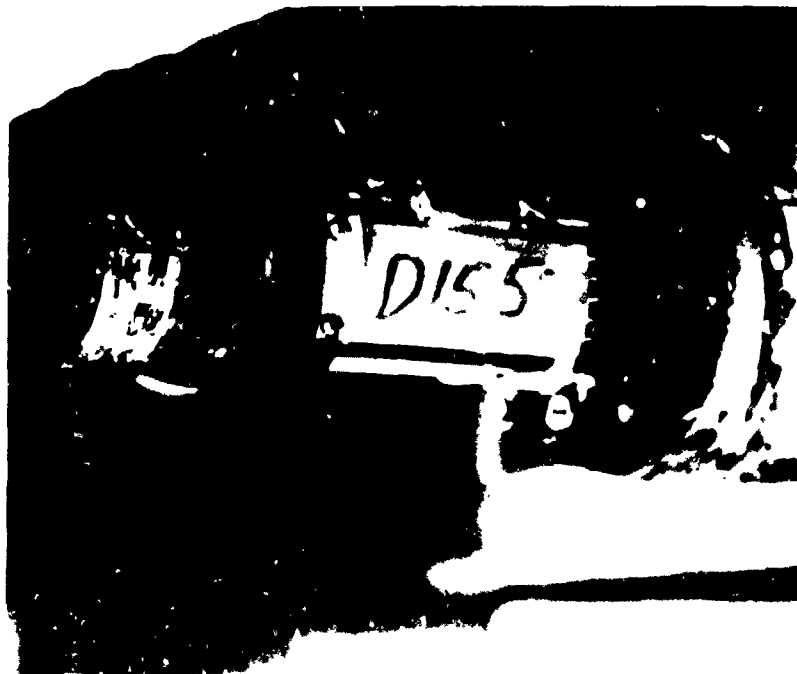


b. AIM-9 S/N RLP 23372
33 kiloamperes applied

Figure 10. AIM-9 Missiles After High Current
Arc Tests Showing Damage to Optical Dome

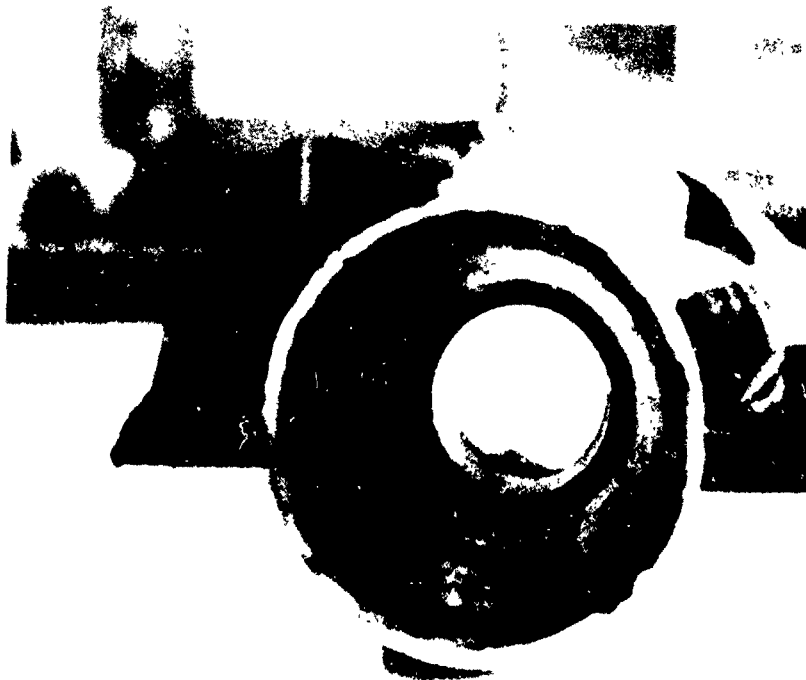


a. Interior of Fiberglass Housing

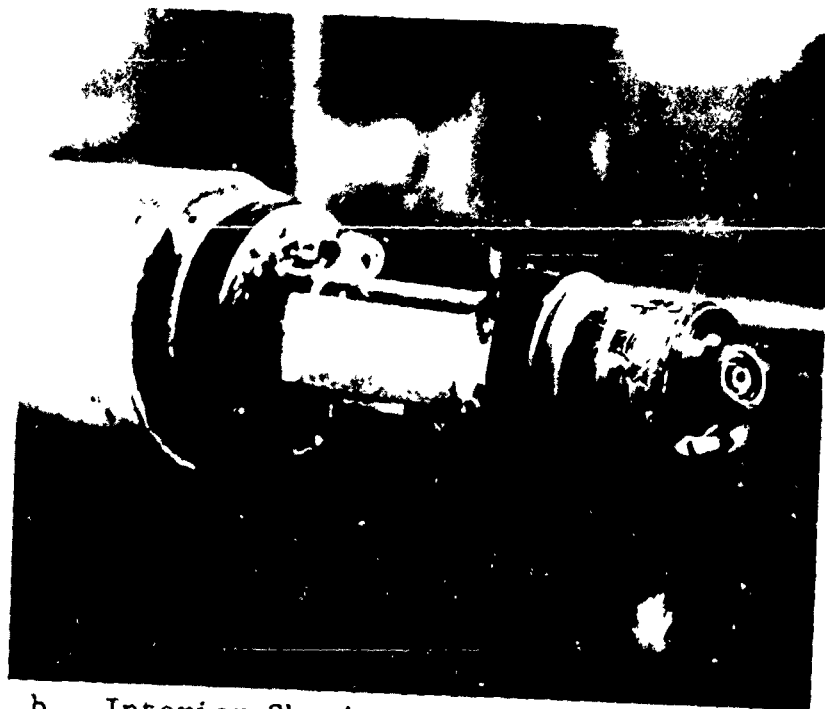


b. Interior Showing Forward Electronics

Figure 11. Interior of AIM-9 Missile, S/N AJ1355M



a. Interior of Fiberglass Housing



b. Interior Showing Forward Electronics

Figure 12. Interior of AIM-9 Missile, S/N RLP23372

SECTION VI

CONCLUSIONS

The arc attachment to the missile was experimentally determined to be at the optical dome/zinc-coated fiberglass interface rim except for one attachment to the optical dome. This single attachment to the dome was forced by reducing the distance of the discharge electrode from 1 meter to 51 centimeters away from the dome. Arcing was observed around the screw heads at the interface of the zinc-coated fiberglass housing and metallic missile housing. The streamering test validated the long arc attachment points. Streamering was evident from the rim at the interface where the optical dome mates with the zinc-coated fiberglass housing.

The optical dome on the AIM-9 missile is vulnerable to simulated lightning strikes even at moderate current levels. The optical dome was shattered and extreme discoloration and burn marks were observed on the zinc-coated fiberglass housing and around the screw heads at the fiberglass/metal interface. This external damage occurred at a peak applied current level of 33 kiloamperes. As mentioned previously, however, when the missiles were disassembled, there was no visual evidence of internal arcing. Therefore, it is unlikely that lightning will directly enter the F16 aircraft via AIM-9 missiles.

Data on energy induced in electrical circuits by lightning indicate concern relative to the operability of the missile subsequent to a strike. Since determining the effects of induced energy on the AIM-9 was not an objective of this test program, no attempt was made to collect comprehensive data. The data collected do show, however, that no potentials were developed to arc over the isolation provided by the control relays. There is a possibility that an induced voltage may be generated during a full scale strike which could produce arcing into aircraft power. However, this would enter only the D.C. non-essential buss. Since no critical electronics are connected to the non-essential D.C. buss, transient voltages on those lines (when the missile is active - isolation relays closed) will not affect aircraft safety.

SECTION VII

RECOMMENDATIONS

Since the induced transients measured on the missile umbilical could have significant effects on missile performance, the organization having primary responsibility for the AIM-9 missiles should determine the possible impacts and needs for further tests or corrective measures.

One measurement that was not made during the test program was monitoring the induced voltages on the missile electrical circuitry during high current simulated lightning tests. It is recommended that future tests of this type include a measurement of induced voltage at the high current levels.

APPENDIX A

HIGH VOLTAGE ARC ATTACHMENT TEST DATA

This appendix contains the photographic documentation for each of the eighteen (18) tests conducted. (Reference Section V of Report)

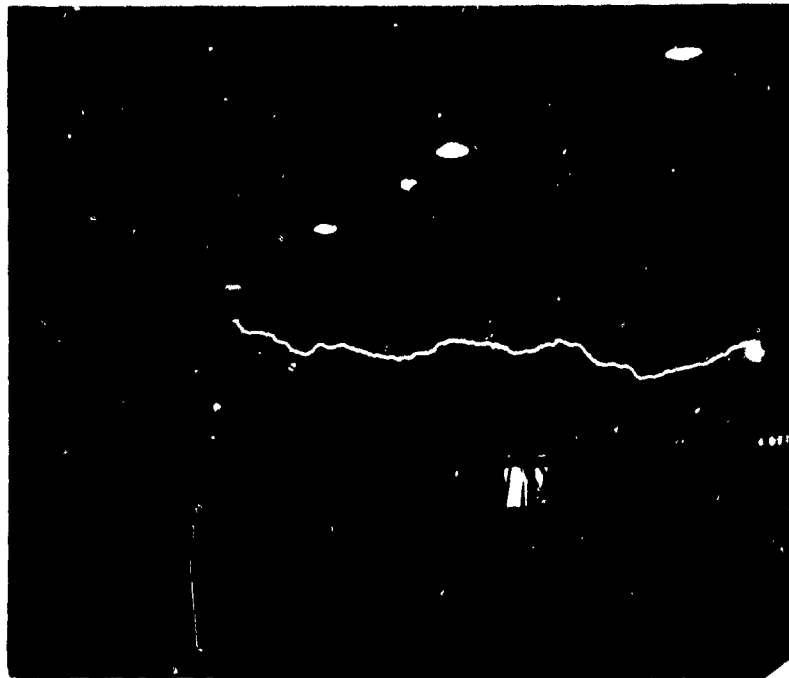


Camera #1

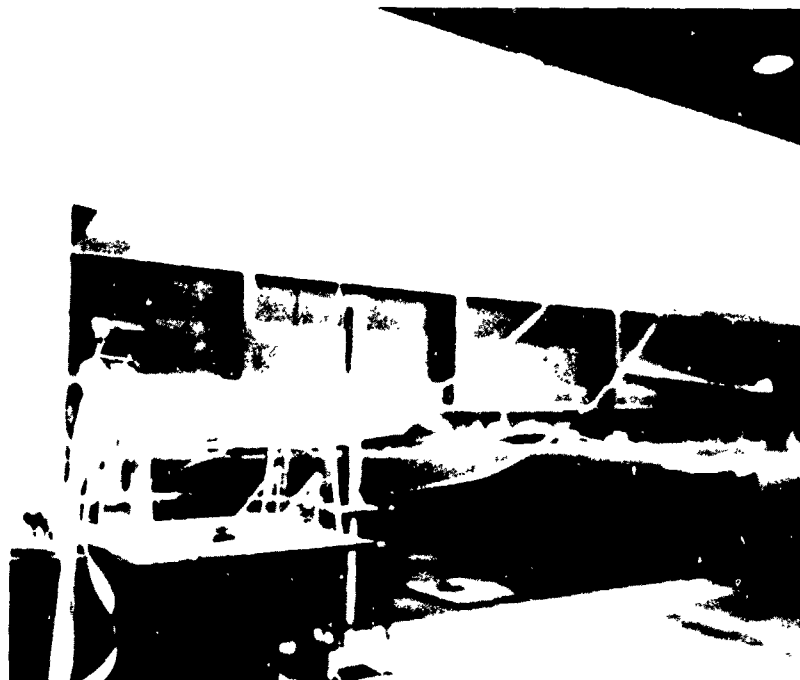


Camera #2

Figure A-1. Arc Attachment to AIM-9 Missile
Test #1, Probe 90°, Horizontal Plane



Camera #1

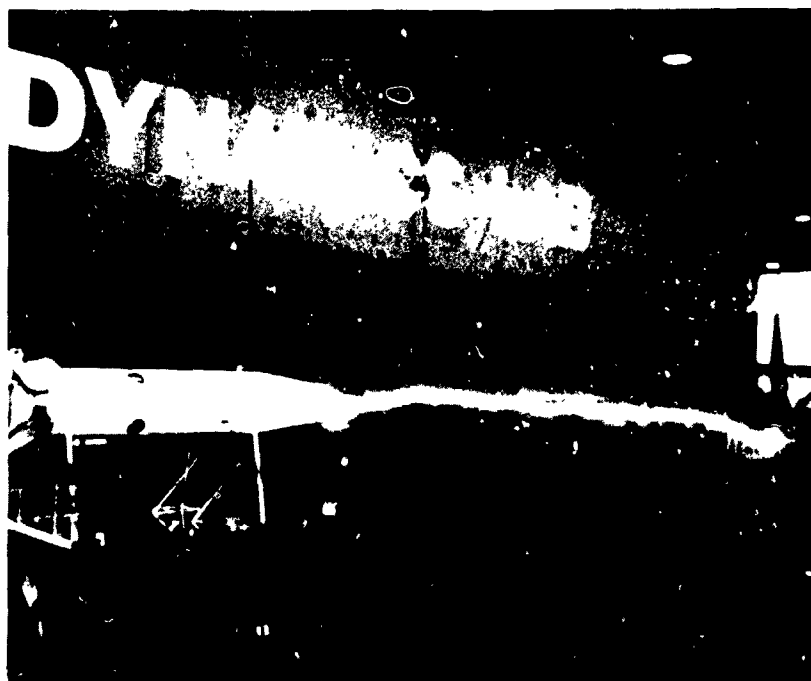


Camera #2

Figure A-2. Arc Attachment to AIM-9 Missile
Test #2, Probe 90°, Horizontal Plane



Camera #1

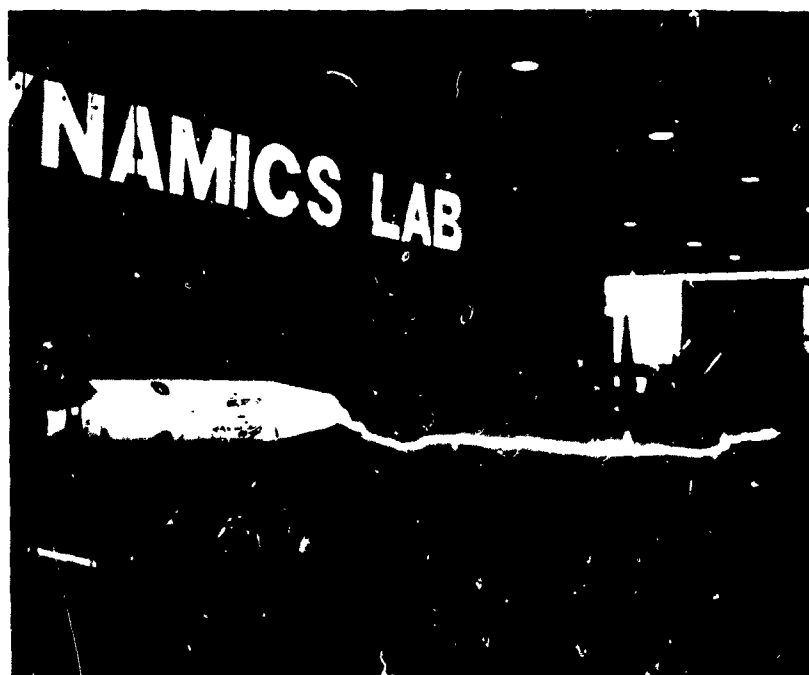


Camera #2

Figure A-3. Arc Attachment to AIM-9 Missile
Test #3, Probe 75°, Horizontal Plane



Camera #1



Camera #2

Figure A-4. Arc Attachment to AIM-9 Missile
Test #4, Probe 60° , Horizontal Plane

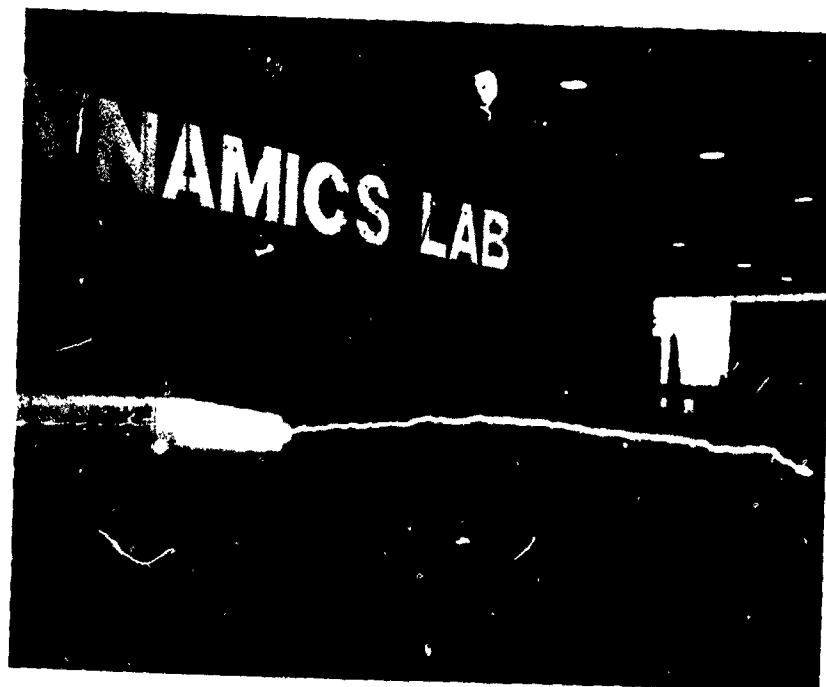
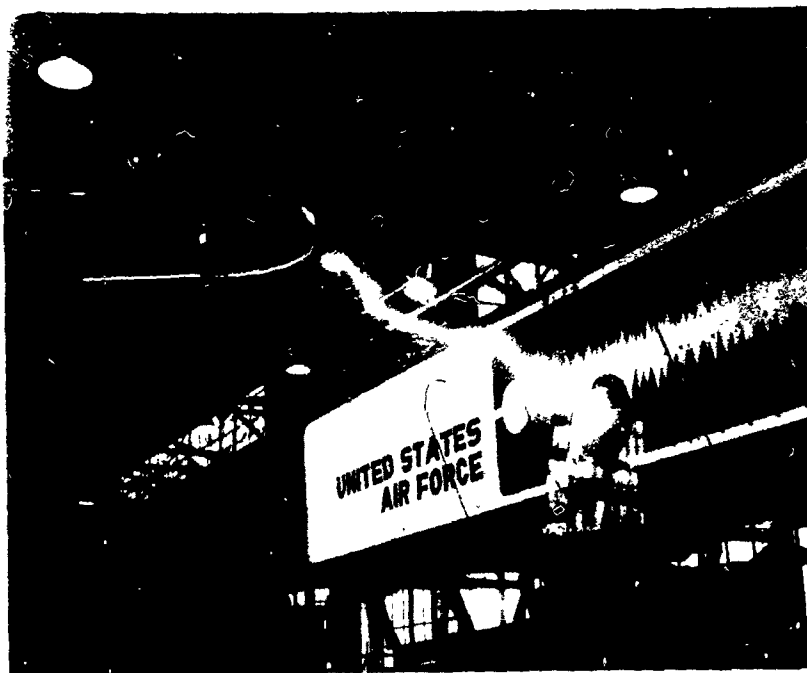
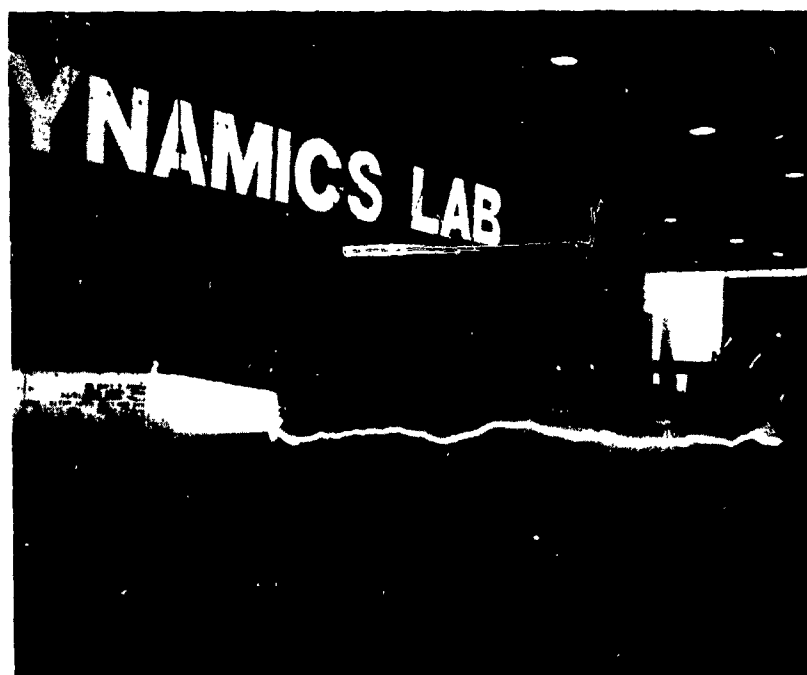


Figure A-5. Arc Attachment to AIM-9 Missile
Test #5, Probe 45° , Horizontal Plane

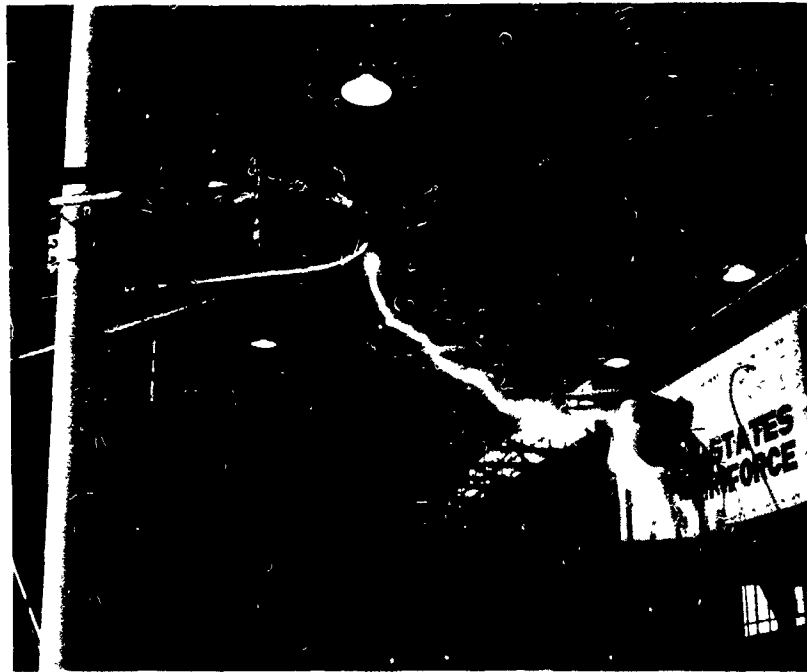


Camera #1

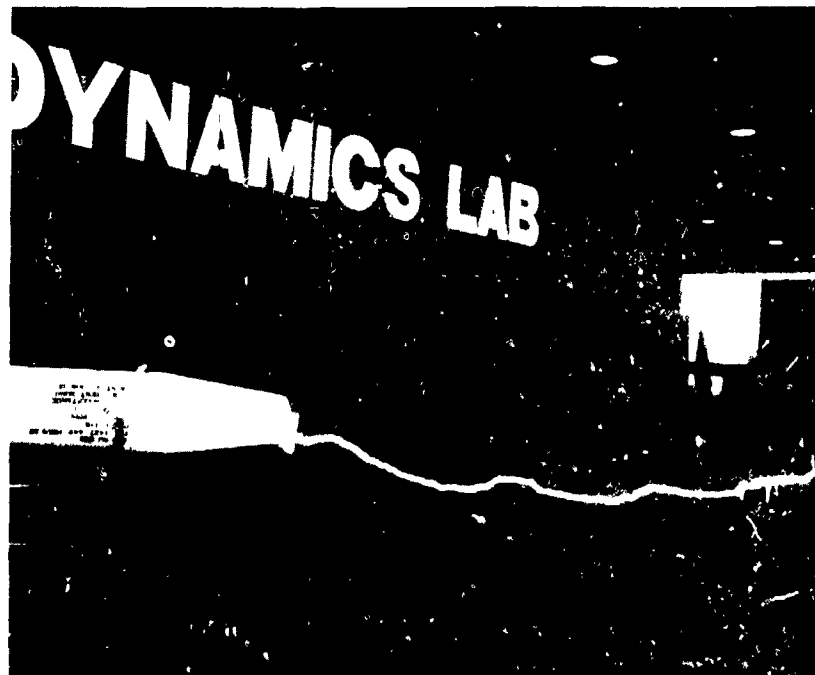


Camera #2

Figure A-6. Arc Attachment to AIM-9 Missile
Test #6, Probe 30°, Horizontal Plane



Camera #1



Camera #2

Figure A-7. Arc Attachment to AIM-9 Missile
Test #7, Probe 15°, Horizontal Plane

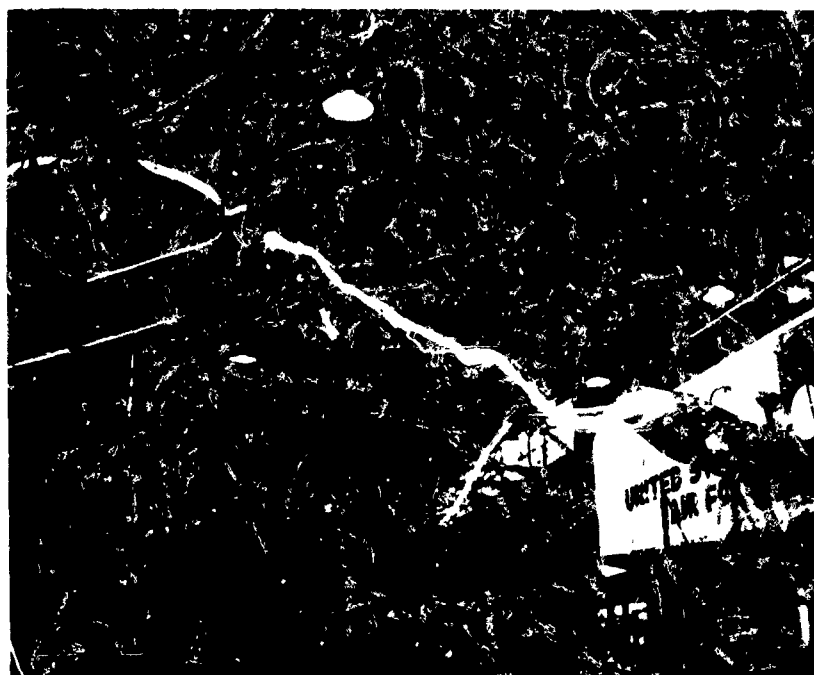
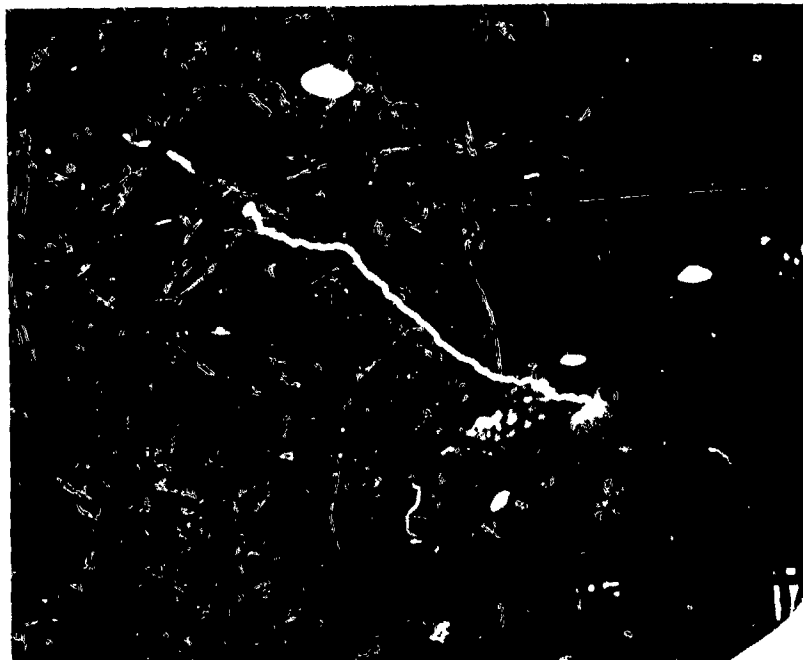
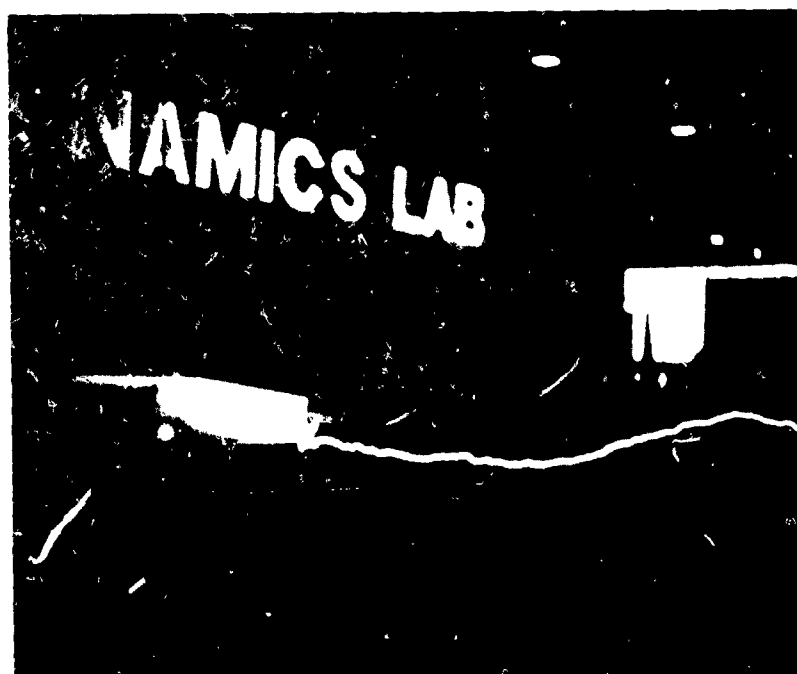


Figure A-8. Arc Attachment to AIM-9 Missile
Test #8, Probe C⁰, Horizontal Plane



Camera #1



Camera #2

Figure A-9. Arc Attachment to AIM-9 Missile
Test #9, Probe 0° Horizontal Plane

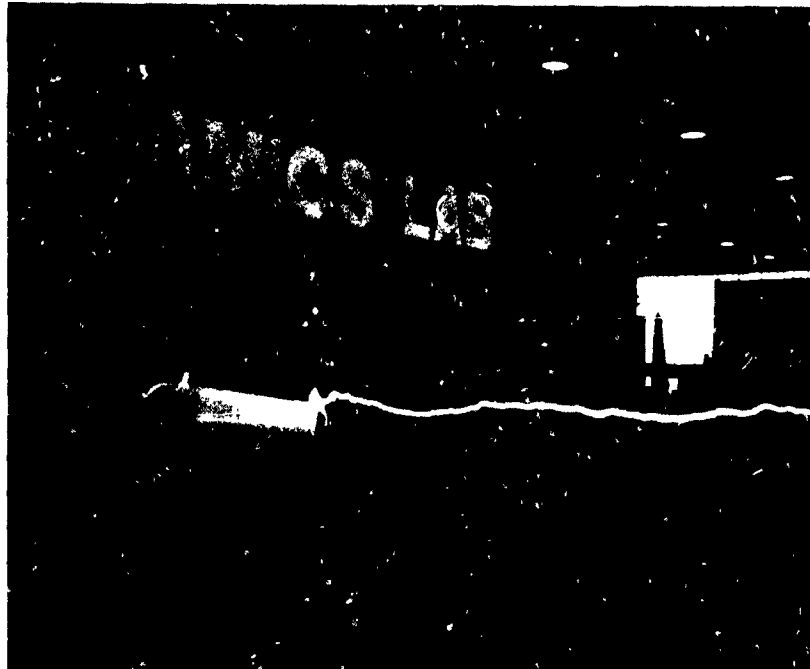
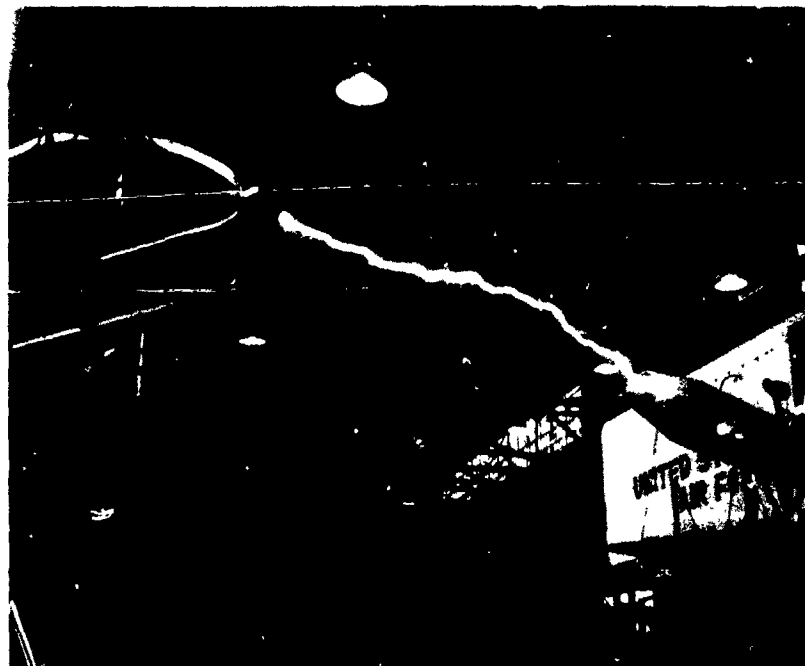
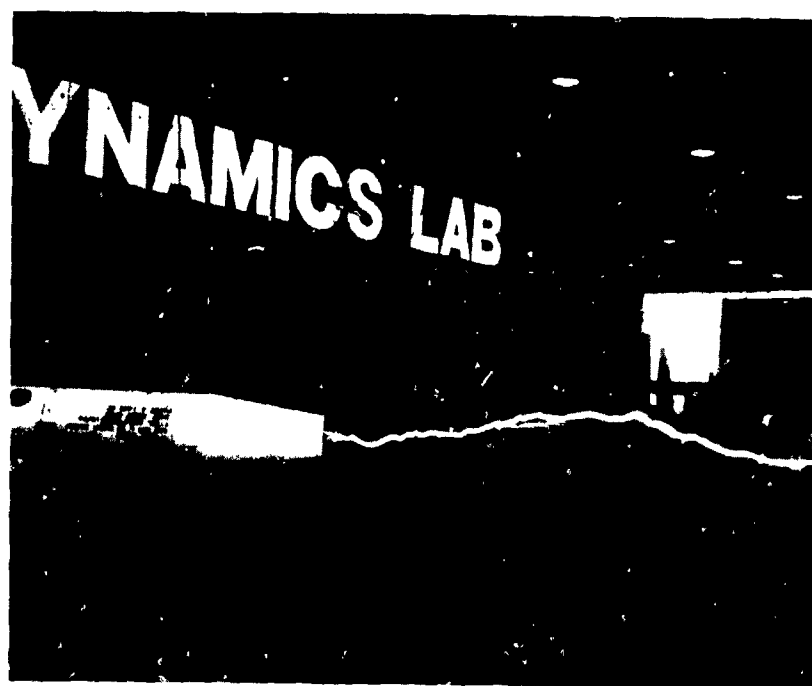


Figure A-10. Arc Attachment to AIM-9 Missile
Test #10, Probe 0°, Horizontal Plane

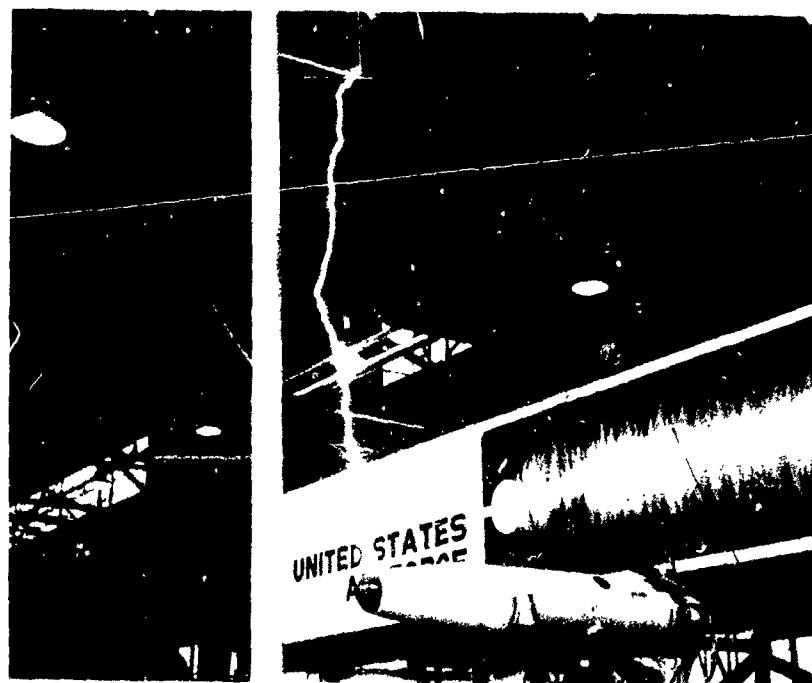


Camera #1

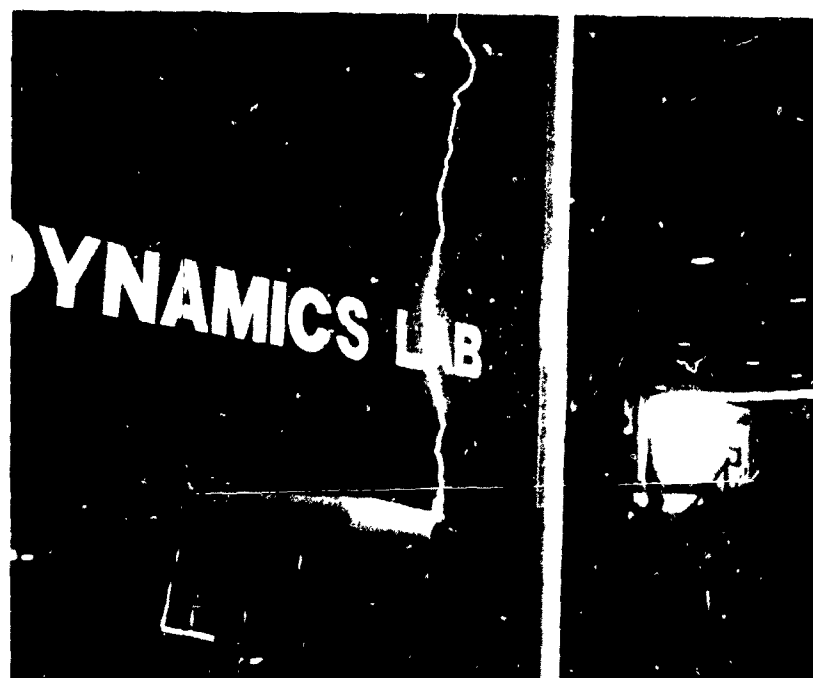


Camera #2

Figure A-11. Arc Attachment to AIM-9 Missile
Test #11, Probe 0° , Horizontal Plane



Camera #1



Camera #2

Figure A-12, Arc Attachment to AIM-9 Missile
Test #12, Probe 90°, Vertical Plane

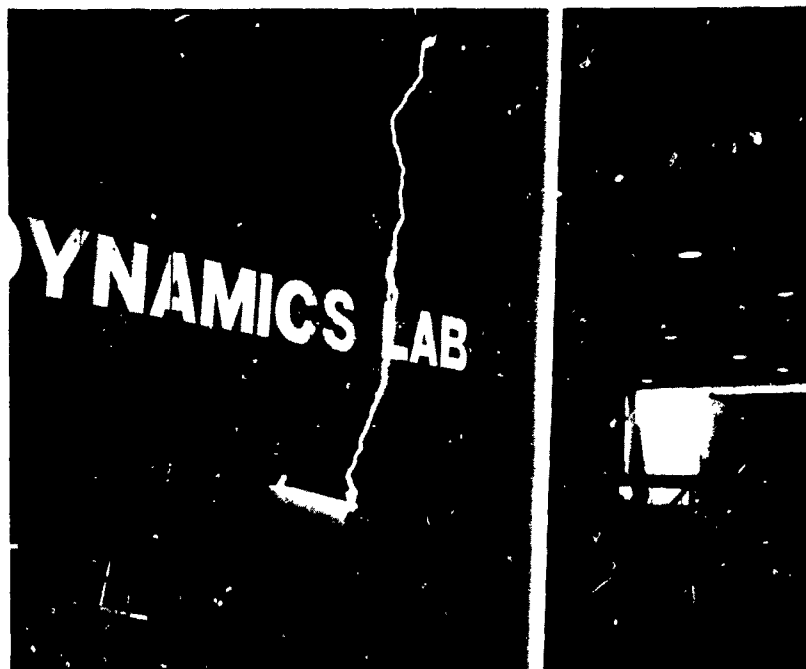


Figure A-13. Arc Attachment to AIM-9 Missile
Test #13, Probe 75° , Vertical Plane



Camera #1



Camera #2

Figure A-14. Arc Attachment to AIM-9 Missile
Test #14, Probe 600, Vertical Plane

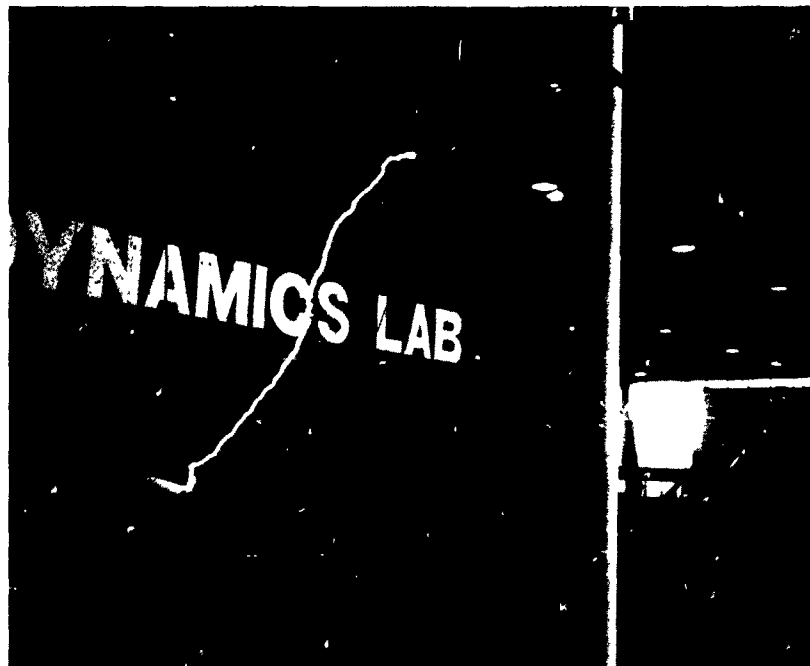
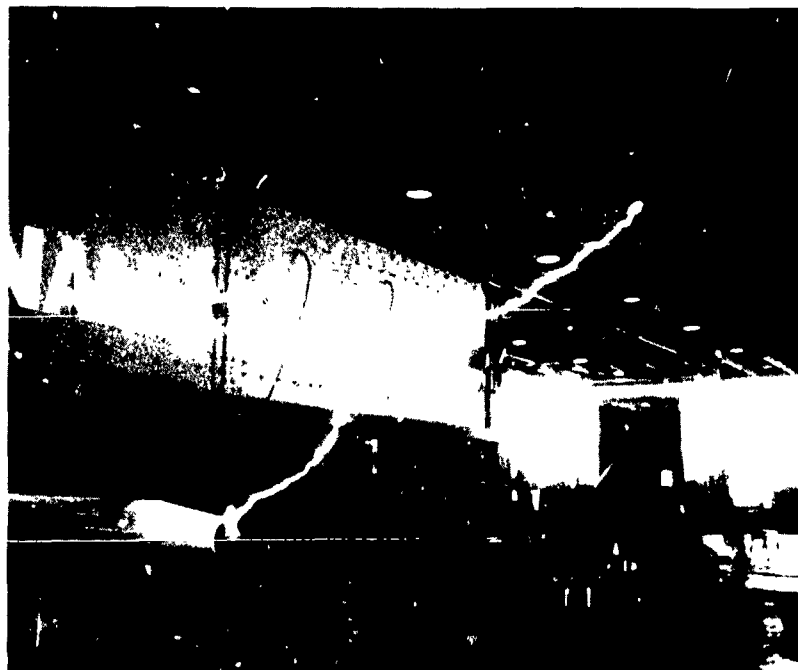


Figure A-15. Arc Attachment to AIM-9 Missile
Test #15. Probe 45°, Vertical Plane



Camera #1

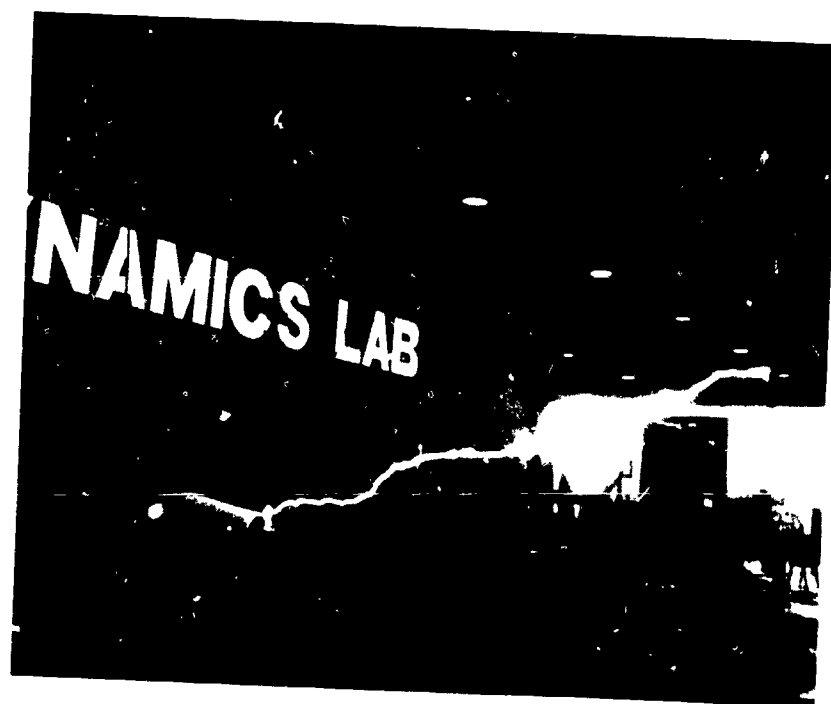


Camera #2

Figure A-16. Arc Attachment to AIM-9 Missile
Test #16, Probe 30°, Vertical Plane

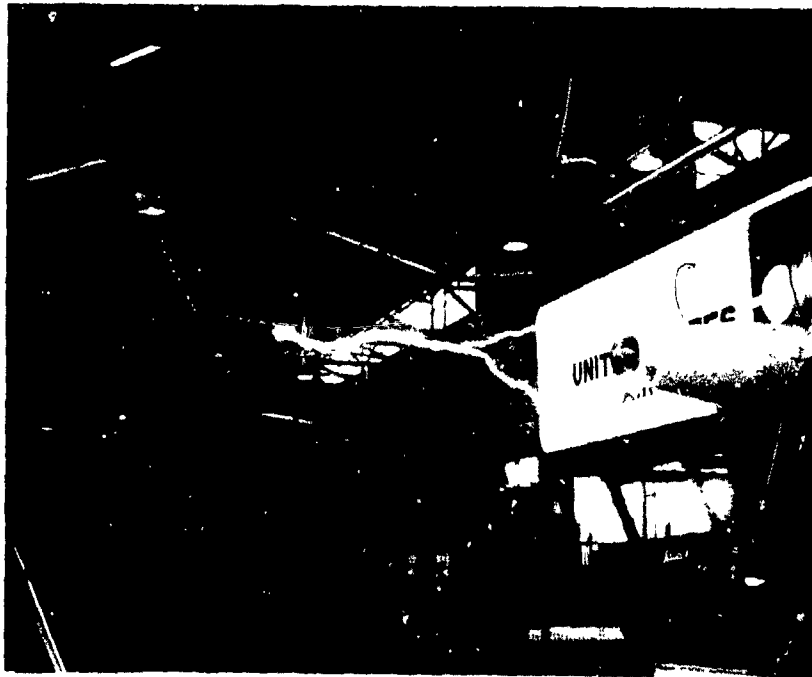


Camera #1

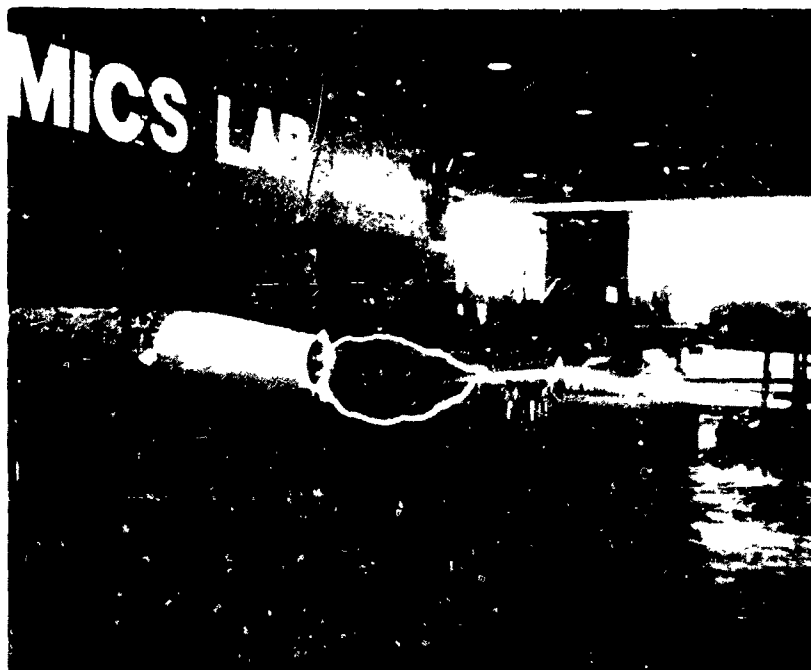


Camera #2

Figure A-17. Arc Attachment to AIM-9 Missile
Test #17, Probe 150, Vertical Plane



Camera #1



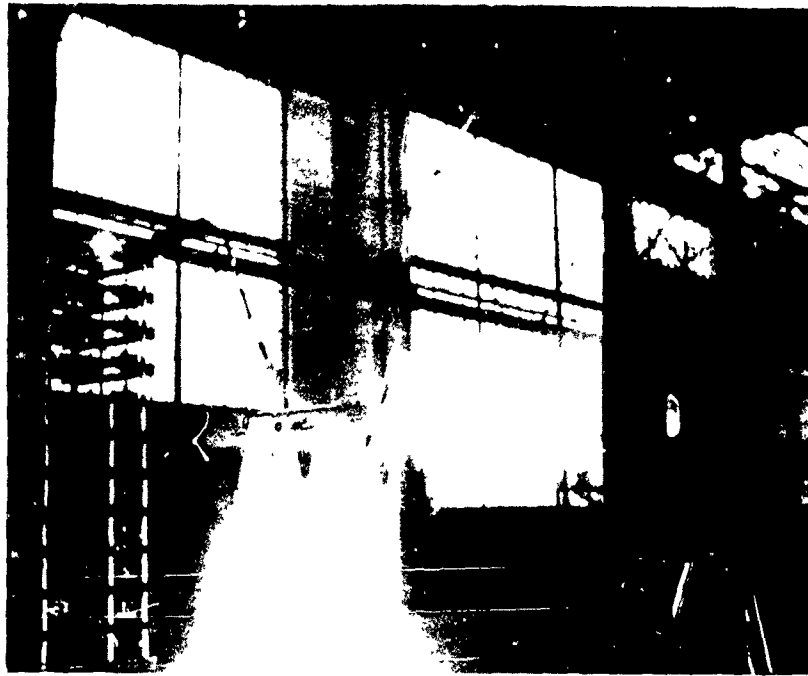
Camera #2

Figure A-18. Arc Attachment to AIM-9 Missile
Test #18, Probe 0°, Vertical Plane

APPENDIX B

STREAMERING TEST DATA

Photographic documentation of the streamering tests (See Section V).

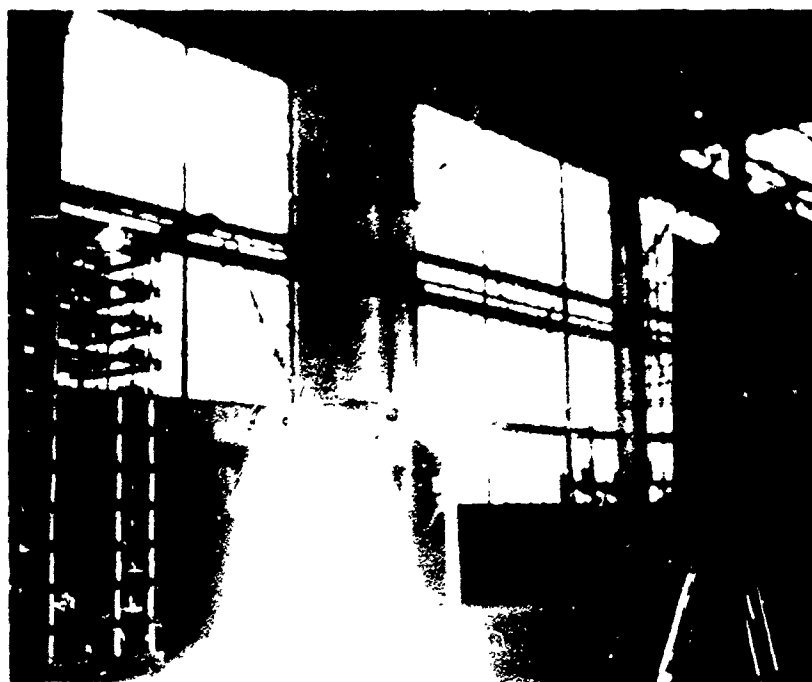


Camera #1



Camera #2

Figure B-1 Streamering from the Interface of the Optical Dome and the Zinc-Coated Fiberglass Housing, Test #1.

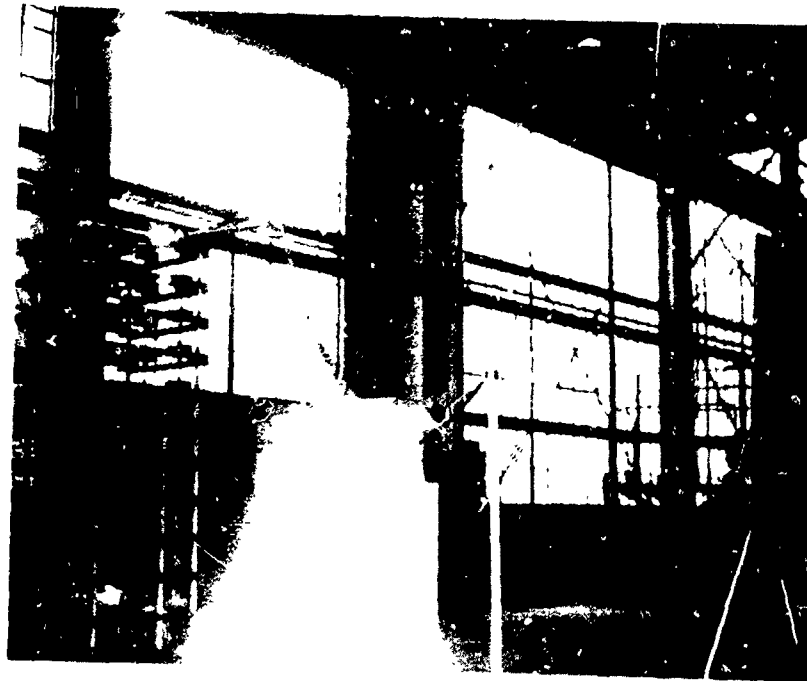


Camera #1



Camera #2

Figure B-2. Streamering from the Interface of the Optical Dome and the Zinc-Coated Fiberglass Housing, Test #2.



Camera #1



Camera #2

Figure B-3. Streamering from the Interface of the Optical Dome and the Zinc-Coated Fiberglass Housing , Test #3.

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